PATENT SPECIFICATION

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(54) IMPROVEMENTS RELATING TO OPTICAL CORRECTION SYSTEMS

(71) We, HARRIES ELECTRONIC CORPORATION, a corporation organised and existing under the laws of the State of Alabama, United States of America of 1914 Montgomery Highway, Dothan, Alabama, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

In Specification No. 897,361 there is described a corrector plate for an optical system in which the image is projected on to a viewing screen at an oblique angle. Obliquely projected images result in keystone distortion and we had found that it was not possible to devise a lens or aspheric plate with a continuous surface to correct for this. The partial differential equations representing the gradients of such a corrector can be calculated but it can be shown that no solution exists in the required form. We had discovered, however, that correction could be achieved by a device previously unknown in optical correction, namely a plate having a surface composed of a number of facets, each varying in slope across its surface, the facets being separated by lines of discontinuity of slope; the gradients of each facet were such that the paths of a bundle of rays arriving at that facet from the object in the optical system were modified so as to displace the points of arrival of the rays at the image surface into such positions that keystone distortion was substantially avoided. This corrector plate was located between the projector and the screen.

One particularly important application of this earlier invention was in colour television, where colour component images have to be combined at a viewing screen. In conventional colour television systems, this is done by means of a tube having a mosaic of different phosphors at its screen, the phosphors fluorescing in red, blue and green, and having separate electron guns in the tube for energising the different phosphors. However, as the electron stream from each gun must energise only the phosphor dots or strips which will fluoresce in a colour corresponding to that represented by the signal applied to the gun, this system requires a very complex form of display tube. An alternative is to have three separate tubes, each responsible for a different colour component image and then to superimpose the images. The disadvantages of such a system were that if semi-reflecting plates were used to superimpose the images, too much light was lost and if the images were projected directly on to a screen there was the problem of keystone distortion, since not more than one tube could be arranged on the optical axis of the screen. This problem of correction of keystone distortion was unresolved prior to the invention forming the subject of Specification No. 897361.

In that specification it was proposed that each tube arranged obliquely to the plane of the screen should have a faceted corrector plate placed between the tube and the screen. This permitted the superimposition of the projected images without keystone distortion. In the preferred form described in this earlier specification, the corrector plate resembled a "flower" with a central plane disc and radially extending "petals". Each petal was formed with gradients varying over its surface and the petals were separated by the lines of discontinuity of slope.

The present invention is based on the realisation that by modifying the geometry of the system not only could the extent of the correction be reduced but also the design of the corrector plates for a multi-projector system could be considerably simplified. To be more specific, according to the present invention in a projection colour television system in which a group of tubes are arranged to project colour component images in superimposition on to an image area of a common screen, the display tubes are arranged in a

group with each tube inclined to an axis meeting perpendicularly the centre of the image area on the screen and between each tube and the screen there is a facetted light-transmitting corrector element having a surface which comprises a number of facets each varying in slope and separated from adjacent facets by lines of discontinuity of slope, the gradients of each facet being such that keystone distortion at the screen is substantially avoided; the corrector elements are parts of a composite corrector plate which extends generally in a single plane perpendicular to the said axis, and which is so arranged that the rays from each tube are confined to the corresponding element of the corrector plate, the gradients of each facet being chosen having regard both to the angle made by the corresponding tube with the said axis and to the different distances between different parts of the corrector element and its tube; each corrector element is symmetrical about a line bisecting that element and passing through the centre of the composite plate and has its facets in the form of strips extending from boundary to boundary of the corrector element. In the preferred form, the screen has a spherical curvature and presents its concave face to the tubes. This reduces considerably the amount of keystone distortion and the gradients and discontinuities on the facetted corrector plate are then less than in our earlier apparatus, and the image quality is improved. In our improved apparatus, we have removed the radial symmetry of the correction; in the earlier design each corrector plate was in a plane normal to its projector axis to preserve this radial symmetry. In apparatus embodying the present invention, there is a single composite plate which is oblique to each projector axis. This corrector plate is easier to make and mount than the separate radially symmetrical plates of the earlier design and this simplification is achieved without sacrificing the benefits resulting from the reduction in the amount of keystone distortion.

The gradients required in the corrector plate may be further reduced by extending the length of the system and thus reducing the field angle. This allows the residual aberrations in the system to be reduced. In addition, each of the different sections of the corrector plate corresponding to the different tubes can now be made simpler in form. In our preferred form, the facets are strips separated by lines of discontinuity of slope which are parallel to one another, the strips in each portion extending in a direction perpendicular to a line passing through the centre of the composite corrector plate and bisecting the said portion.

In order that the invention may be better understood, one example will now be described with reference to the accompanying drawings, in which:—

Figure 1 is a diagram of the arrangements of two tubes and the corrector plate in relation to the screen;

Figure 2 shows the shape of the corrector plate;

Figure 3 illustrates in greater detail a single section of the corrector plate and Figure 4 shows this section in end view;

Figure 5 is a contour diagram of one section of the plate, prior to shaping of its ends; and

Figure 6 shows diagrammatically a four section corrector plate.

In the example to be described with reference to Figures 1 to 5, three tubes are spaced around the axis of a curved picture screen so that, viewed from the screen along the screen axis, they appear to be at angles of 120° to one another. Figure 1 shows diagrammatically in side elevation some elements of the optical projection system of two of the tubes 2 and 4, together with the corrector plate 6 and the screen 8. Figure 2 is an end view of the arrangement from behind the screen. Thus, in Figure 1 the angle made by the axis of the upper tube 2 with the picture screen axis is shown correctly but a line joining the picture screen axis to the axis of the lower tube 4 would be oblique to the plane of the paper and consequently the angle shown in Figure 1 is only the component in the plane of the paper.

There is of course a third tube which is not shown in Figure 1 since it is directly behind the tube 4. These three tubes are fed from conventional colour television receiver circuits 9.

The elements shown for each tube are a phosphor screen 10, a concave reflector 12, both within the tube, and an optical stop 14 and a meniscus lens 16 outside the tube. The concave mirror has a central aperture to permit an electron beam from a gun at the back of the tube to reach the phosphor screen 10. The reflecting side of the mirror 12 faces the phosphor 10 so that light from the latter is reflected by the concave mirror back past the phosphor screen and through the optical stop 14 and the meniscus lens 16. The phosphor screen 10 has a slight tilt (about 1° in the example shown) with respect to the axis of the tube.

The corrector plate 6, which is common to all the tubes, extends in a plane perpendicuar to the main axis. The radius of curvature of the screen is substantially equal to the distance between the screen and the plane of the centres of the optical stops 14.

The shape of the composite corrector plate 6 is shown in Figure 2. Figure 2 also shows the locations of the phosphor screens 10, which lie behind the corrector plate. It will be seen that the corrector plate has three limbs, one for each tube. The geometry of the

system is such that rays from each tube are substantially confined to the section of the corrector plate provided for that tube.

Each section of the corrector plate consists of a number of parallel strips extending perpendicularly to a line bisecting that section and passing through the centre of the composite corrector plate. One surface of each strip or facet varies in slope from point to point in a continuous manner and the junctions between facets constitute lines of discontinuity of slope. One section of the corrector plate is illustrated in greater detail in Figures 3 and 4. The section consists of seven strips numbered 4, 3, 2, 1, 0, −1, −2, and −3. Light from the tube reaches the plate in the direction of the arrow *a* (Figure 4). Although Figure 4 shows clearly the discontinuities in slope at the junctions of these strips or facets, it cannot show the detail of these slopes. To illustrate this more clearly, we have shown in Figure 5 the contours of a corrector plate section. The dotted lines represent contours of constant thickness, the values given indicating the difference between the actual thickness and a reference thickness in millimetres. A positive value indicates an increase in plate thickness above the reference.

The formulae governing the thickness of the plate at any point are given below. In these formulae z represents the difference between the actual thickness and the reference thickness, y represents distances along a line passing through the centre of the corrector plate and bisecting the section shown and x represents distances along the corrector plate parallel to the strips. All distances are in millimetres. The zero values for x and y are shown in Figures 3 and 5. The strip equations are:—

Strip		
4	($y=45$ to 90):	$z=0.5-0.0124y+0.00000344x^2y-0.000345x^2$
3	($y=35$ to 45):	$z=0.3-0.0085y+0.00000344x^2y-0.000276x^2$
2	($y=25$ to 35):	$z=0.0053y+0.00000344x^2y-0.000207x^2$
1	($y=15$ to 25):	$z=0.0029y+0.00000344x^2y-0.000138x^2$
0	($y=-15$ to $+15$):	$z=0.00000344x^2y$
−1	($y=-30$ to -15):	$z=-0.0001y+0.00000344x^2y+0.000155x^2$
−2	($y=-45$ to -30):	$z=-0.0020y+0.00000344x^2y+0.000259x^2$
−3	($y=-88$ to -45):	$z=-0.0049y+0.00000344x^2y+0.000345x^2$

In this example, the reference thickness is 5 millimetres. The corrector plate was of a transparent plastics material having a mean refractive index of 1.492.

In this example, the meniscus lens 16 was of hard crown optical glass and had an inner radius of 44 millimetres and an outer radius of 55 millimetres. The phosphor screens 10 had a convex surface with a radius of 54 millimetres and the aluminised concave mirror had a radius of 125 millimetres. The phosphor screen size was 28×21 millimetres and it had a tilt of one degree. The distance from the centre of the concave mirror to the centre of the phosphor screen was 71.15 millimetres; from the centre of the convex surface of the phosphor screen to the aperture stop was 53.85 millimetres; from the aperture stop to the centre of the concave surface of the meniscus lens was 44 millimetres; and from the aperture stop to the centre of the screen was 950 millimetres. The screen had its image surface concave to the tubes. A magnification of 17.6 was obtained.

Figure 6 shows a composite corrector plate designed for a four tube assembly. Such an assembly might be used, for example, if the efficiency of one of the phosphors was substantially below the efficiencies of the other two phosphors in a three colour system. In such a case, two tubes having the low efficiency phosphors might be used in order to provide a better balance in light output with the other two tubes.

It will be appreciated that the gradients of the facets vary with the dimensions and angles of the system. In designing a system of this kind, one first decides the number of tubes to be employed. Next the size of the picture screen is decided and from this is determined the size of the phosphor screens, because the phosphor can only give a certain maximum power density of light output before it saturates. In this way, the magnification from phosphor screen 10 to picture screen 8 is obtained. The next step is to decide the throw or projection distance, which governs the field angle of each projector. This choice in turn reacts on the off-axis angle of each projector system.

One also has a choice between a flat screen and a curved screen. A moderate screen curvature facilitates the design because there is less correction to be done and consequently the corrector plates are easier to make. The position of the corrector plate in relation to the screen and tubes is then settled. This is not very critical. The plate must be far enough from the aperture stop of each tube (the centre of curvature of the aluminised mirror) to ensure that different parts of the corrector plate act on " pencils " of rays from different parts of the phosphor screen. It must also be far enough from the image plane to permit the

bending of the rays accomplished by the corrector plate to have an effect in displacing the points of arrival of the rays at the screen. There is a range of intermediate positions which the corrector plate could occupy and in practice the furthest position from the tubes consistent with the general guidance given above seems to be the best choice.

The slope or gradient of each facet is calculated by the usual methods of numerical computation used by those skilled in the optical art. A series of principal rays is calculated and the rays are traced from the optical object to the screen (excluding for the moment the corrector element) at different distances from the axis. The distortion is calculated, including barrel and pincushion distortion as well as keystone distortion. This must be done at sufficiently close spacings to give enough data for computing the facets. Rays must be taken in a number of meridian planes at suitable angles to that one which is perpendicular to the centre of the screen.

Next, for any given ray the point at which it ought to have met the screen if there had been no distortion is found and from this it is possible to calculate the inclination to the normal which the surface of the corrector plate should have at the point at which this ray meets it. This is done by applying Snell's law of refraction to find the required wedge angle of the corrector facet, knowing the index of refraction of the material from which the plate is to be made. To reduce astigmatism, it is better to have this angle on the side of the corrector plate nearer to the viewing screen if there is pincushion distortion to be corrected in addition to keystone distortion; if there is barrel distortion it is better to have the angle on the side of the plate nearer the tubes.

The wedge angle is then determined for each facet by interpolating as necessary between the angles found for the principal rays traced. The number of facets is chosen by arranging that the jump in ray deviation between neighbouring facets corresponds to less than one picture point on the screen.

WHAT WE CLAIM IS:—

1. A colour television display system comprising a number of display tubes, each corresponding to a different colour component of the colour television system, a common screen having an image area for receiving in superimposition individual images projected in different colours from the said display tubes, the display tubes being arranged in a group with each tube inclined to an axis meeting perpendicularly the centre of the image area of the screen, and a facetted light-transmitting corrector element between each tube and the screen, each corrector element having a surface which comprises a number of facets each varying in slope and separated from adjacent facets by lines of discontinuity of slope, the gradients of each facet being such that keystone distortion in the image at the screen is substantially avoided, and in which the facetted corrector elements are parts of a composite light-transmitting corrector plate which extends generally in a single plane perpendicular to the said axis, and which is so arranged that the rays from each tube are confined to the corresponding element of the corrector plate, the gradients of each facet being chosen having regard both to the angle made by the corresponding tube with the said axis and to the fact that different parts of the corrector element serving each tube will be at different distances from the tube, each corrector element being symmetrical about a line which bisects that element and passes through the centre of the composite corrector plate and having its facets in the form of strips which extend from boundary to boundary of the corrector element.

2. A colour television display system in accordance with Claim 1, in which for each corrector element, the facets are parallel strips extending in a direction perpendicular to the said line bisecting the element and passing through the centre of the corrector plate.

3. A colour television display system in accordance with Claim 1 or 2, in which the screen is curved so as to present a concave face to the tubes.

4. A colour television display system in accordance with Claim 1, substantially as herein described with reference to the accompanying drawings.

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1235344 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

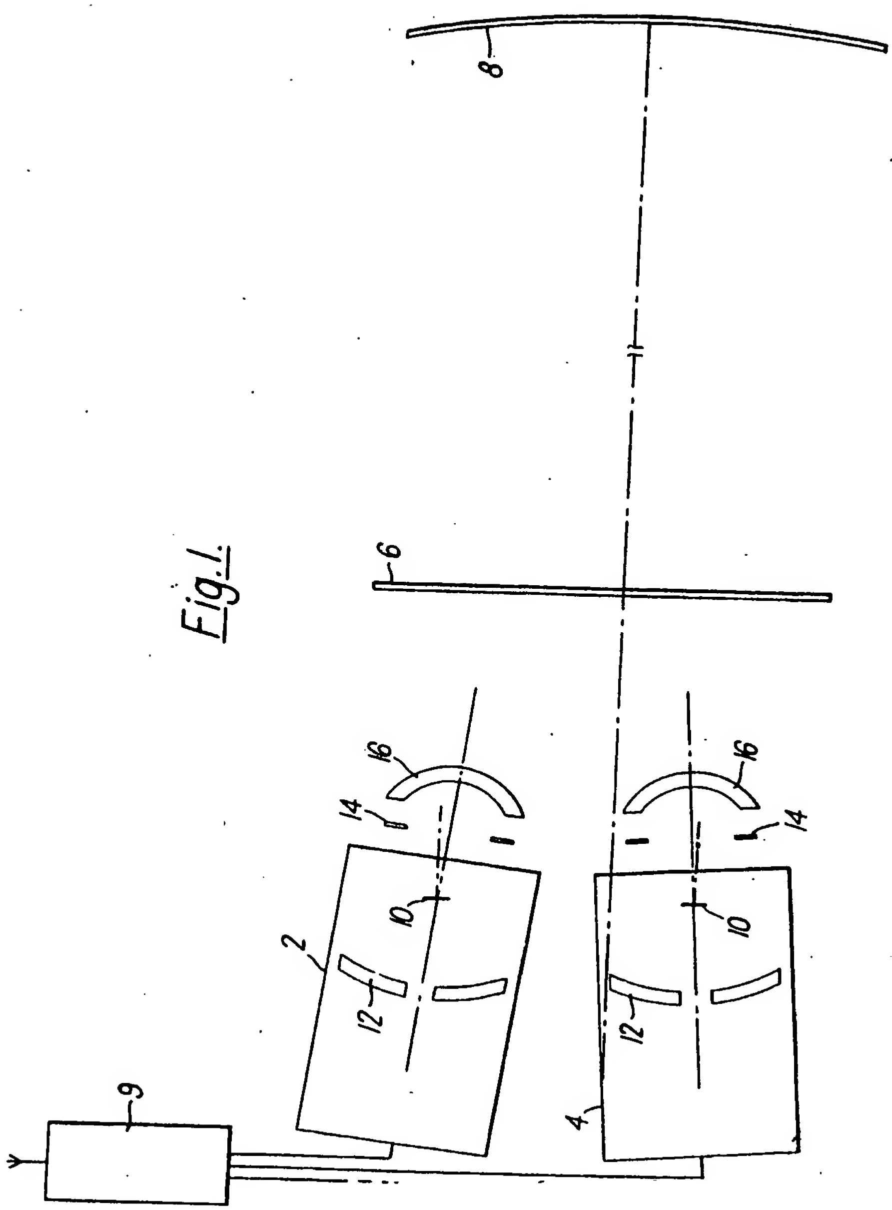

Fig.1.

1235344 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

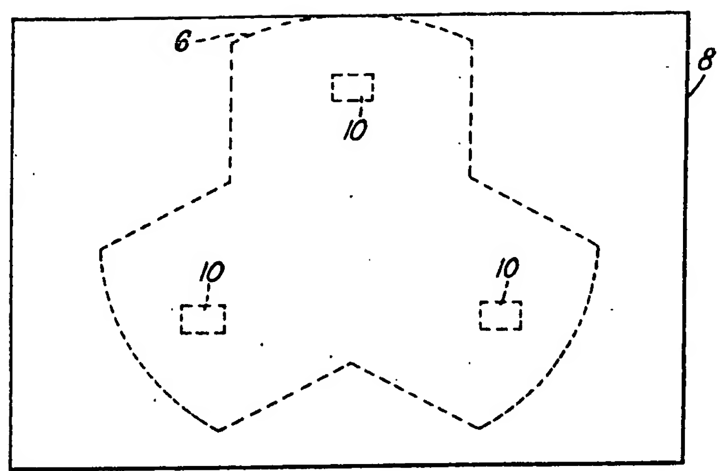

Fig. 2.

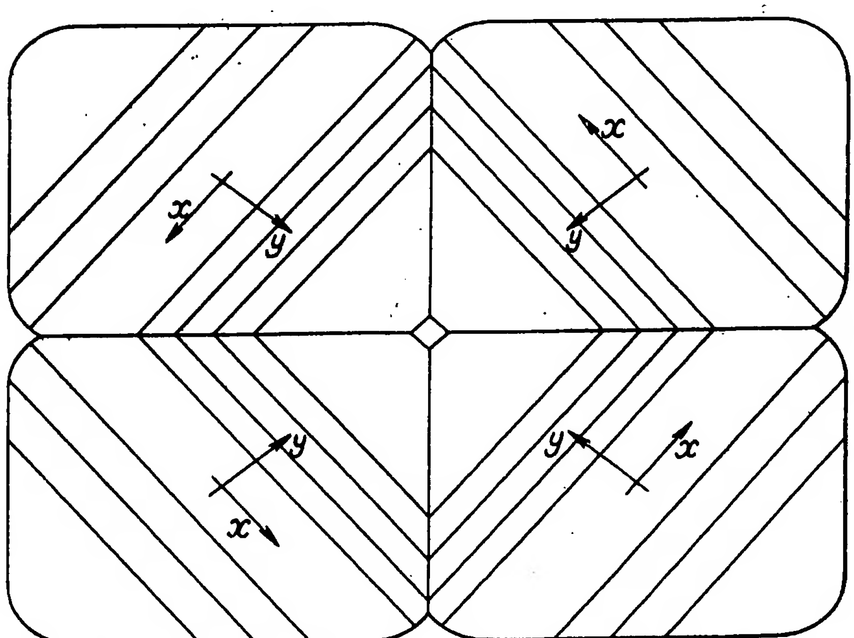

Fig. 6.

1235344 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

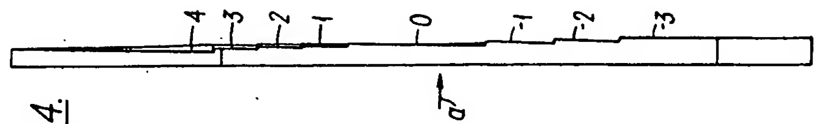

Fig.4.

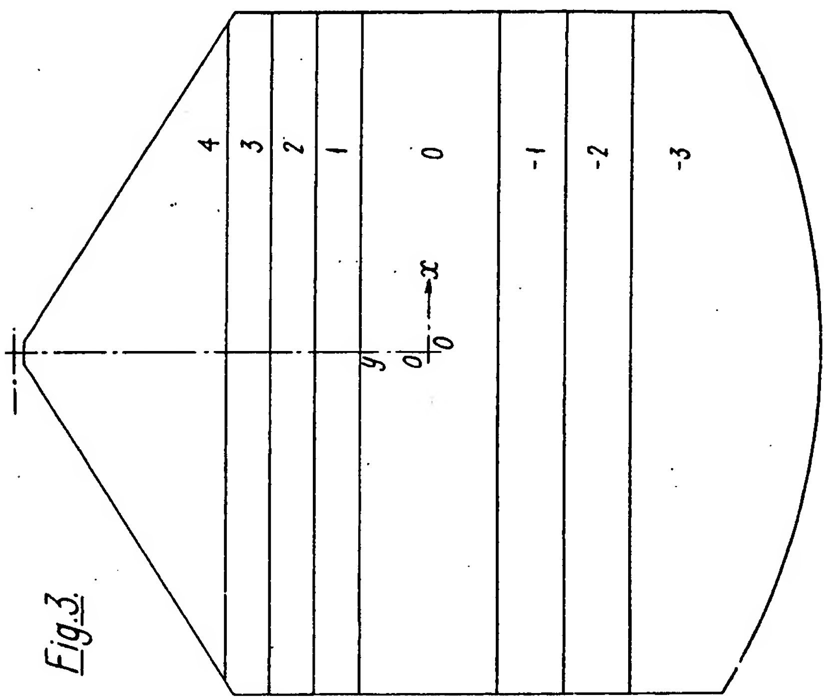

Fig.3.

1235344 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

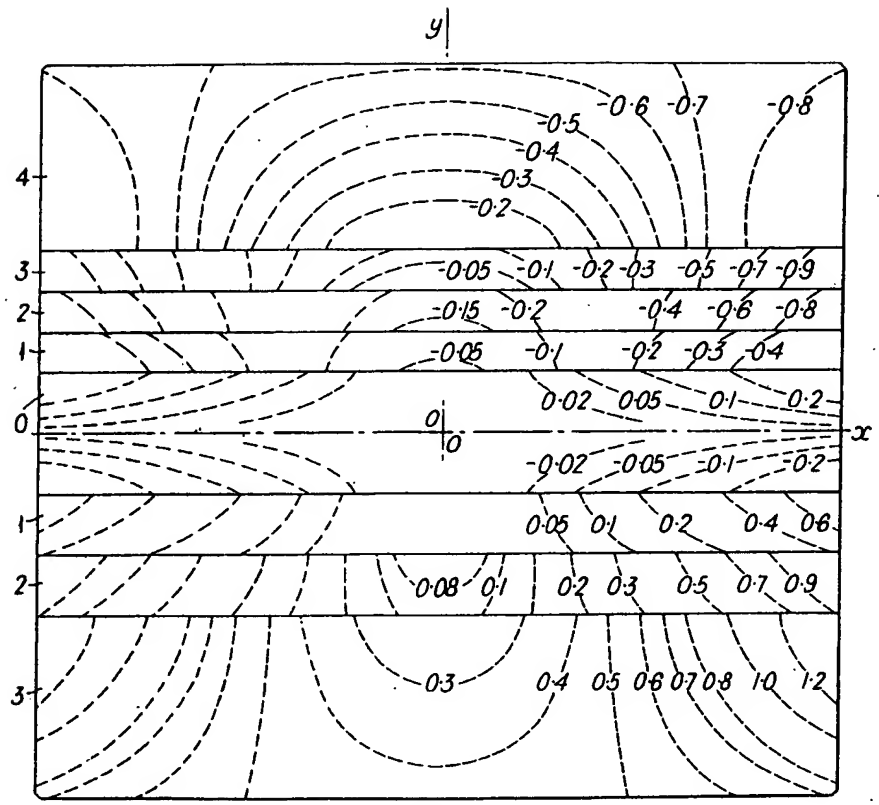

Fig.5.